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Associations of *Salmonella* hospitalizations with ambient temperature, humidity and rainfall in Hong Kong

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ABSTRACT

Background: Little is known about the relationship between *Salmonella* infection and meteorological parameters other than air temperature. This study aimed to explore associations of *Salmonella* hospitalizations with temperature, relative humidity (RH) and rainfall.

Methods: With negative binomial distribution assumed, time-series regression model adjusting for season and time trend were constructed employing distributed lag non-linear models and generalized additive models. Meteorological variables including mean temperature, RH, and daily total rainfall as well as indicator variables including day of the week and public holiday were incorporated in the models.

Results: Higher temperature was strongly associated with more hospitalizations over the entire range of temperatures observed. There was a net 6.13 (95%Confidence Interval (CI) 3.52–10.67) relative risk of hospitalization at a temperature of 30.5 °C, relative to 13 °C, lag 0–16 days. Positive associations were found for RH above 60% and rainfall between 0 and 0.14 mm. Extreme high humidity (96%) and trace rainfall (0.02 mm) were associated with 2.06 (95%CI 1.35–3.14), lag 0–17 day, and 1.30 (95%CI 1.01–1.67), lag 0–26 days, relative risks of hospitalizations, relative to 60% and no rain, respectively.

Conclusions: High temperatures, high RH and light rainfall are positively associated with *Salmonella* hospitalizations. The very strong association with temperatures implies that hotter days will lead to increases in *Salmonella* morbidity in the absence of other changes, and the public health implications of this could be exacerbated by global climate change.

1. Introduction

The earth is warming up, and the world has been alerted to the mounting threat of climate change (The Lancet, 2014). The impact of climate change on the distribution and spread of infectious diseases is of significant public health concern.

Non-typhoidal *Salmonella* infection, also known as salmonellosis, is caused by *Salmonella* species other than *Salmonella* Typhi and *Salmonella* Paratyphi, and is one of the most widespread foodborne diseases (fecal-oral transmission can also occur) with tens of millions of cases occurring every year all over the world (World Health Organization, 2013). It has been estimated that 93.8 million gastroenteritis cases and 155,000 associated deaths occur yearly worldwide (Majowicz et al., 2010). In a nine-year investigation between 2003 and 2011 in Hong Kong, of the 4230 bacteria-caused food poisoning outbreaks reported to the Centre for Health Protection, 763 were associated with non-typhoidal *Salmonella*, and a total of 3250 persons were affected, ranking it the second most common bacterial agent of food poisoning outbreaks in Hong Kong during that period (Centre for Health Protection, 2011). However, the worsening situation from 2011 to 2017 has already made it the most common bacterial causative agent among confirmed cases of food poisoning (Centre for Health Protection, 2017).

Most prior studies of associations between *Salmonella* and meteorological variables have focused on temperature (Lake et al., 2009; Fleury et al., 2006; Zhang et al., 2010; Britton et al., 2010; Uejio, 2017; Jiang et al., 2015; Akil et al., 2014). Higher temperatures have consistently been found to be associated with higher incidence of *Salmonella* infection, although association magnitudes and lengths of lagged effects have varied (Lake et al., 2009; Fleury et al., 2006; Zhang et al.,

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2010; Britton et al., 2010; Uejio, 2017; Jiang et al., 2015; Akil et al., 2014). The association of *Salmonella* infection with relative humidity (RH) and rainfall has been less well studied. A few studies from Australia have examined rainfall, with conflicting results reported (Zhang et al., 2010; Stephen and Barnett, 2016; Zhang et al., 2008), with positive associations being reported for Brisbane and Townsville (Zhang et al., 2010) and Queensland (Stephen and Barnett, 2016) while a negative association was found in Adelaide (Zhang et al., 2008). Another study in Maryland, USA found that exposure to extreme precipitation 90th percentile was associated with a 5.6% increase in the risk of salmonellosis (Jiang et al., 2015). A recent study from Singapore reported a 1% increase in the mean RH was associated with a 1.3% decrease in reported cases six weeks later. However, no cumulative association was assessed and the use of weekly data might not capture the true lag dependency (Aik et al., 2018). Accordingly, the present study aimed to investigate associations between hospitalizations for non-typhoidal salmonellosis and RH, rainfall, and temperature in Hong Kong, a subtropical Chinese city.

2. Methods

Hong Kong has a total area of 1106.34 km^2 and a total population of 7.34 million as of 2016 (Hong Kong Special Administrative Region Government, 2018). Daily counts of admissions of *Salmonella* infection from January 1st, 2002 through December 31st, 2011 from all public hospitals in Hong Kong were obtained from the Hong Kong Hospital Authority and extracted and reclassified according to primary discharge diagnosis from The International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM, code for non-typhoidal salmonellosis: 003.0), Sixth Edition. Daily values of meteorological variables including daily means of temperature, RH, and daily total rainfall for the same period were retrieved from the Hong Kong Observatory.

Time-series regressions were used to model hospitalizations for *Salmonella* infection as a function of mean temperature, mean RH and daily total rainfall. Distributed lag nonlinear models (DLNMs) (Gasparrini, 2011), with the capability of assessing potentially nonlinear exposure-response dependencies and their delayed effects at the same time, were constructed together with generalized additive models (GAMs) (Wood, 2006), with a negative binomial distribution assumed to account for over-dispersion. Day of the week and public holiday (government-designated days off with the exclusion of Sundays) in Hong Kong were incorporated as indicator variables in all models, while day of the year and day of the study period were included as smooth terms of thin plate regression splines with certain degrees of freedom (*df*), respectively, to adjust for seasonality and long-term trend. The model family can be formulated as follows:

$$\log[E(Y_t)] = \beta_0 + \sum cb(\text{meteorological variables}, df_1, \text{lag}, df_2) + s(\text{DOY}, df_3) + s(t, df_4) + factor(\text{DOW}) + factor(\text{holiday})$$

where $E(Y_t)$ is the expected daily count of *Salmonella* infection admissions on day t; t is the day of the study period from 2002 through 2011; β_0 is the intercept; *cb()* represents the crossbasis function in the distributed lag models describing the potential exposure-response and lag-response associations with their corresponding degrees of freedom; *s()* denotes a thin plate penalized spline function; DOY represents day of the year adjusting for seasonality; DOW and holiday represent indicator variable for day of the week and binary variable for public holiday, respectively. The maximum lag was defined as 21 days for mean temperature and RH, and 30 days for total rainfall. The longer lag for rainfall was employed as the authors felt that there could be an extended time window between rainfall and drinking water or food contamination that could impact on pathogen transmission (Wang et al., 2016). Moreover, this impact could be further delayed due to the determent of heavy rainfall for people from seeking medical care. Three to six degrees of freedom were tried for the crossbasis and spline functions to assess the model robustness and the goodness-of-fit among the models were compared and validated using the regression coefficient (R^2) and Akaike's information criterion (AIC). All results, summing up all the contributions from the first day (same day) of the environmental exposure up to the maximum lag, were reported as the relative risk (RR) of a chosen percentile value of certain meteorological variable with corresponding 95%confidence interval (CI), compared to a pre-defined reference value. If a linear or approximately linear association was found, the 3rd percentile of the value of the variable would be used as the reference value. If a hockey-stick-shaped association was identified, the value with the lowest risk would be adopted. As for rainfall, all RRs were calculated relative to no rain for ease of interpretation. All statistical analyses were performed in R software version 3.3.0.

3. Results

A total of 4828 hospitalizations (including 6 deaths) due to *Salmonella* infection were reported from January 1st 2002 through December 31st 2011, among which 3396 cases were recorded during six hottest months in Hong Kong (from May through October). Of all hospitalizations, 2665 (55.2%) patients were male, and 2858 cases (59.2%) occurred among children aged 1 year old or younger, 1395 (28.9%) were aged 2–14 years, 225 (4.7%) were between 15 and 44, 129 (2.7%) were between 45 and 64, 70 (1.4%) were 64–74, and 151 (3.1%) were 75 or older (a total 575 (11.9%) were 15 years old or older). Descriptive statistics for daily cases of *Salmonella* infection and conditions for mean temperature, RH and daily total rainfall are summarized in Table 1. Fig. 1 shows the time series of daily counts of admissions of *Salmonella* infection and of the three meteorological parameters during the entire study period. There was a clear summer peak of *Salmonella* infection and most of the rain fell during the same season.

Six and four degrees of freedom were chosen for day of the year and day of the study respectively since they best captured seasonality and time trend throughout the study period. Fig. 2 depicts the duration of effects of extreme values (99th percentile) of weather variables (and trace rainfall for total rainfall), with a maximum lag of 21 days for mean temperature and RH and 30 days for total rainfall. The positive association between high temperature (30.5 °C, 99th percentile) and *Salmonella* hospitalizations persisted for 16 days, with a reference temperature of 13 °C. Very high RH (96%) was modestly associated with fewer hospitalizations for the first three days (lag 0–2) but positively

Table 1
Descriptive summary for hospitalizations of *Salmonella* infection, mean temperature, mean relative humidity and daily total rainfall in Hong Kong from 2002 through 2011.

	Mean (SD)	Min.	P[a] (1st)	P (25th)	Median	P (75th)	P (99th)	Max.
Salmonella hospitalizations	1.3 (1.3)	0	0	0	1	2	5	9
Length of stay (days)	4.3 (4.1)	1	1	2	3	5	16	94
Mean temperature (°C)	23.5 (5.1)	8.2	11.3	19.4	24.6	27.8	30.5	31.8
Relative humidity (%)	78 (10.3)	31	47	73	79	85	96	98
Daily total rainfall (mm)	6.2 (20.7)	0	0	0	0.01	1.4	100.4	307.1

[a] P represents percentile.

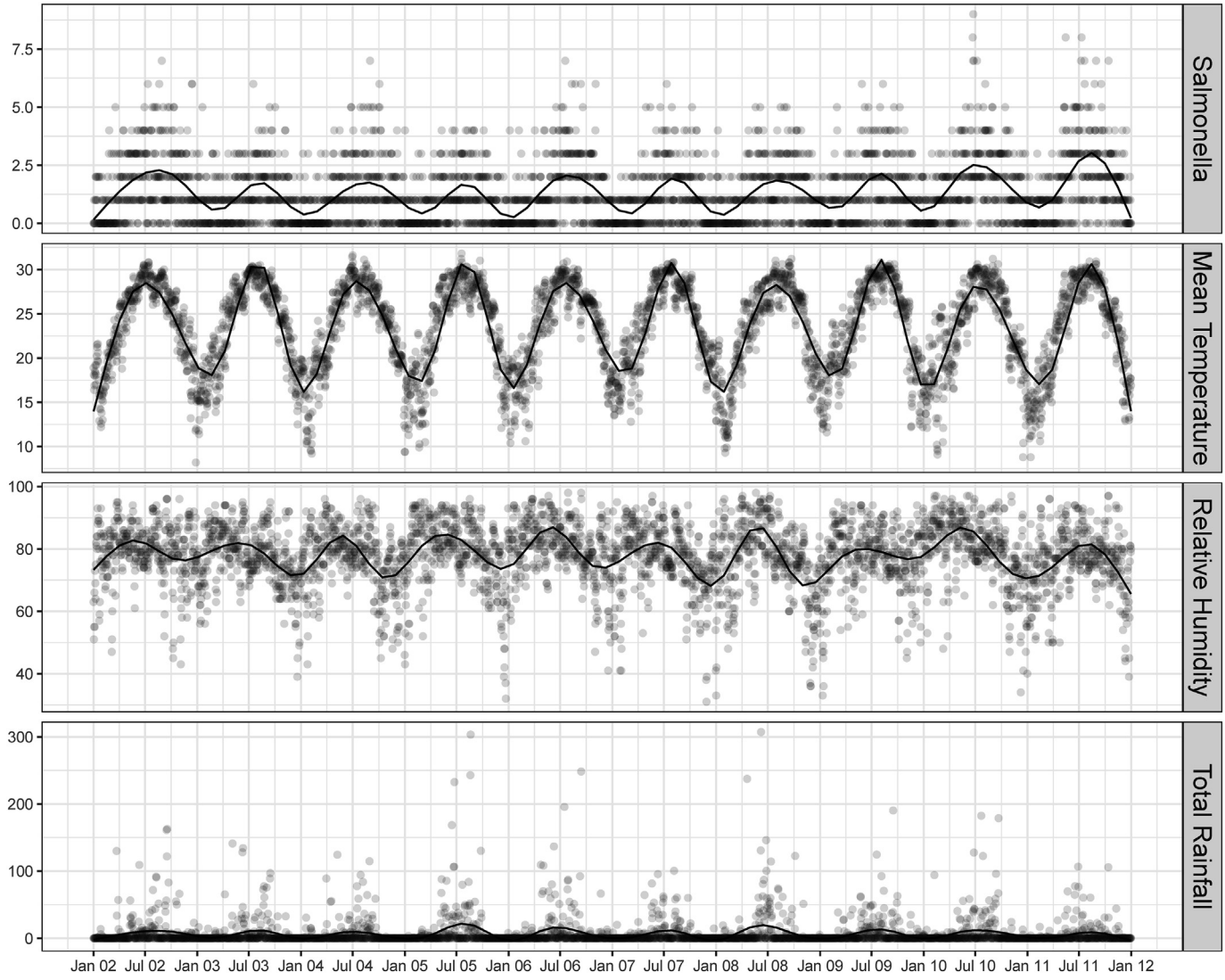

Fig. 1. Time trend for hospitalizations of *Salmonella* infection, mean temperature, relative humidity and daily total rainfall in Hong Kong, 2002–2011.

associated with hospitalization risk for the following 15 wettest days (day 3–17), with the 10th day having the highest RR. Regarding rainfall, heavy rain, 99.5 mm per day, was positively associated *Salmonella* infection for the first 6 days (day 0–5) but negatively associated this disease for day 6–30. However, this association was only statistically significant during the 15th-22nd lagged day.

The corresponding cumulative RRs of *Salmonella* hospitalization with the change in these three meteorological parameters, summing up all the contributions up to the chosen lag time, together with their 95%CIs, are presented in Fig. 3. Higher mean temperature was strongly positively associated with *Salmonella* hospitalizations over the entire range of temperatures observed. Relative to 13 ˚C, there was a 6.13 (95%CI 3.52–10.67) times the risk at a temperature of 30.5 ˚C. A hockey-stick shaped association was found between RH and *Salmonella* hospitalizations, with the RR notably rose above humidity of 60%. Relative to 60%, 85% (75th percentile) RH was associated with 1.45 (95%CI 1.13–1.87) times the risk of hospitalizations for a duration of 17 days. The association with extremely high RH (99th percentile, 96%) was stronger for the same lag, with an RR of 2.06 (95%CI 1.35–3.14) compared with the same reference. In terms of precipitation, more hospitalizations were observed for small amounts of rainfall relative to none, with 0.02 mm and 0.14 mm associated with 1.30 (95%CI 1.01–1.67) and 1.34 (95%CI 0.98–1.84) times the risk of hospitalizations, respectively. However, hospitalizations declined with heavier rainfall. The detailed cumulative effects of temperature, RH (75th and 99th percentile) and total rainfall (trace rainfall and 99th percentile) with *Salmonella* hospitalizations for some defined lags are summarized in Table 2.

Age appeared to be a significant effect modifier in terms of the association of *Salmonella* hospitalizations with meteorological variables, as shown in Fig. 4. The positive association with temperature was stronger in children aged 0–1 and 2–14 than in the adult group, with an RR of 6.72 (95%CI 3.51–12.86), 9.00 (95%CI 4.36–18.56) and 3.34 (95%CI 1.36–8.18) respectively at a temperature of 27.8 ˚C versus 13 ˚C. However, hospitalization risk dropped with temperature above 27 degrees among children aged 2–14 years. The positive association with RH above 60% and the inverse-V association with total rainfall, which were found in the overall analysis for the whole population, was only found among infants in age-specific subgroup analysis.

4. Discussion

The current study found that high temperatures, high RH and light rainfall were positively associated with *Salmonella* hospitalizations in Hong Kong.

A positive association between temperature and *Salmonella* infection has been found in earlier studies (Lake et al., 2009; Fleury et al., 2006; Zhang et al., 2010; Britton et al., 2010; Uejio, 2017; Jiang et al.,

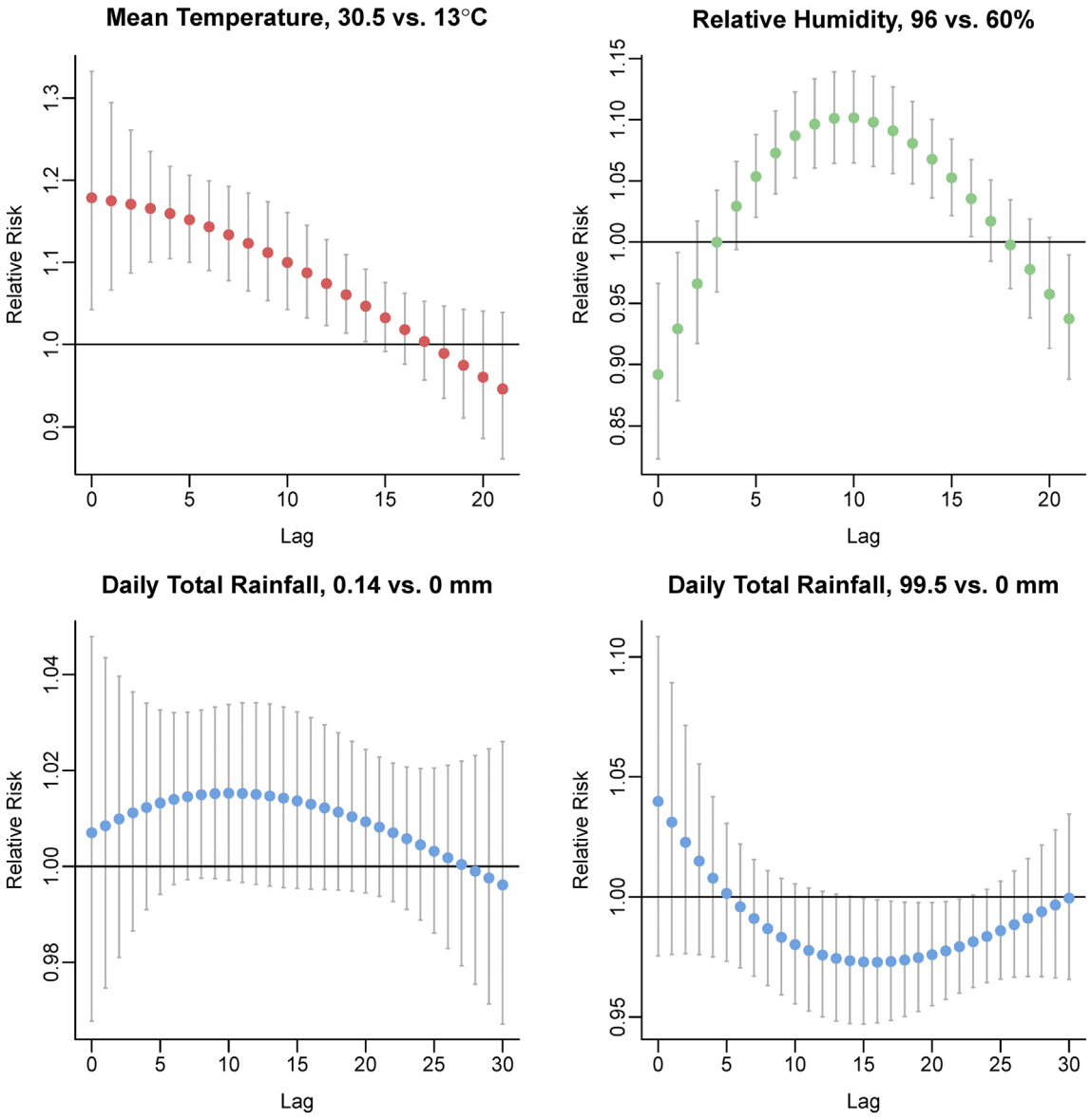

Fig. 2. Lag-response associations of *Salmonella* hospitalizations with mean temperature, relative humidity and daily total rainfall.

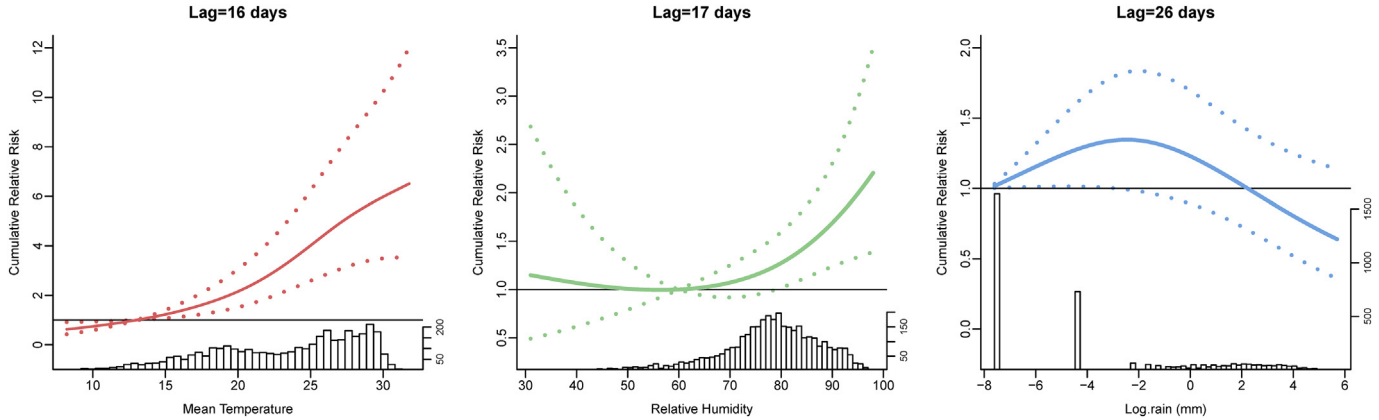

Fig. 3. Cumulative exposure-response associations of *Salmonella* hospitalizations with mean temperature, relative humidity and daily total rainfall with their distributions.

Table 2
Cumulative associations of mean temperature, relative humidity and total rainfall[a] with *Salmonella* hospitalizations by lag period.

	2 days	5 days	17 days	26 days
Mean temperature (27.8 vs. 13 °C)	1.49[b] (1.15, 1.92)	2.18[b] (1.52, 3.12)	5.33[b] (3.27, 8.70)	N/A
Mean temperature (30.5 vs. 13 °C)	1.62[b] (1.21, 2.17)	2.52[b] (1.68, 3.79)	6.15[b] (3.52, 10.76)	N/A
Relative humidity (85 vs. 60%)	0.86[b] (0.77, 0.96)	0.89 (0.75, 1.05)	1.45[b] (1.13, 1.87)	N/A
Relative humidity (96 vs. 60%)	0.80[b] (0.66, 0.97)	0.87 (0.65, 1.15)	2.06[b] (1.35, 3.14)	N/A
Total rainfall (0.02 vs. 0 mm)	1.01 (0.93, 1.10)	1.04 (0.91, 1.19)	1.22 (0.98, 1.52)	1.30[b] (1.01, 1.67)
Total rainfall (99.5 vs. 0 mm)	1.10 (0.93, 1.29)	1.12 (0.87, 1.46)	0.88 (0.59, 1.32)	0.73 (0.45, 1.20)
Total rainfall (99.5 vs. 0.02 mm)	1.08 (0.90, 1.30)	1.08 (0.81, 1.44)	0.72 (0.46, 1.12)	0.56[b] (0.33, 0.96)

[a] The 75th and 99th percentile of mean temperature and RH, and trace (log.rain = −4) and 99th percentile of rainfall were used for extraction of RR, relative to a specific reference.
[b] Significant results.

2015; Akil et al., 2014; Aik et al., 2018), among which some reported an effect lag (Lake et al., 2009; Fleury et al., 2006; Zhang et al., 2010; Britton et al., 2010; Uejio, 2017). There was a 5.4% increase in salmonellosis laboratory reports with 1-degree increase in temperature in the current and previous week in England (Lake et al., 2009). In Alberta, Canada, it was found that the log RR of *Salmonella* infection increased by 1.2% with every degree increase in weekly temperature (Fleury et al., 2006). In Brisbane, Australia, a subtropical city, 1 °C rises in weekly maximum and minimum temperature was associated with 8.8% and 5.8% increase in the weekly number of cases respectively (Zhang et al., 2010). However, in Townsville that has a tropical climate, 1 °C rise in monthly maximum and minimum temperature was associated with 11.9% and 5.9% increase in the weekly number of cases, respectively (Zhang et al., 2010). In a pooled study in Mississippi, Tennessee, and Alabama, USA, it was found that a 1 °F increase in temperature was associated with a 3% increase in *Salmonella* infections (Akil et al., 2014), corresponding to a 5.6% increase for a 1 °C temperature rise. Recently a study from Singapore found 1 °C increase in temperature was associated with a 4.3% and 6.3% increase in reported cases in the same week and three weeks later, respectively (Aik et al., 2018). Our finding of an RR = 6.13 for 30.5 vs. 13 °C corresponds to an 11% increase in hospitalizations per 1 °C increase in mean temperature, which is on the high side of reported effect sizes. A previous laboratory study revealed both *Salmonella* growth rate on fish fillet and its total RNA abundance that intrinsically controls gene regulation and virulence expression were significantly higher at an ambient temperature of 45 °C and room temperature than −20 and 4 °C (Kumar et al., 2015). In addition, previous studies have reported *Salmonella* growth rate in eggs as an increasing function of storage temperature ranging from 7 to 29 °C (World Health Organization, 2002). Another potential explanation could be better *Salmonella* colonization and growth in broiler flocks inducing higher enteritis rate due to poultry product consumption, as well as the waste and feces from broilers that might contaminate nearby water sources and soil (Jiang et al., 2015). Apart from the proliferation and survival of *Salmonella* in the environment that can be directly affected by ambient temperature, the alteration of eating habits (more picnics, barbecues, etc.) during warmer days that has a higher chance of inadequate cooking practices could be another way of temperature influencing *Salmonella* transmission. Apart from undercooked food, consumption of raw or cross-contaminated food that is prone to the influence of ambient temperature during its production, transport and storage has also been one of the most consistent risk factors for contracting *Salmonella* (Centre for Health Protection, 2011; Uejio, 2017).

There have been very few previous epidemiological studies on the association of RH with *Salmonella* infection. A recent study from Singapore using weekly data found a negative association between RH of the current week and reported *Salmonella* cases six weeks later, with no significant associations for the other lag weeks considered (Aik et al., 2018). This is quite different from our result which showed a strong positive association between RH and *Salmonella* hospitalizations at lags 5–16 days. The discrepancy might be due to differences in climate (Singapore has a tropical climate with consistently hot and humid conditions year-round) and differences in methodology. The Singapore study used weekly data, and considered individual lagged terms for each week, up to 6 weeks (Aik et al., 2018), whereas our study used daily data, and used distributed lag terms to model lagged associations. In addition, the Singapore study considered all reported laboratory confirmed, non-travel and non-outbreak associated cases (Aik et al., 2018), while our study used hospitalizations, and thus may be considered as modeling the most severe cases.

There have been some laboratory studies. It has been found that growth or survival of *Salmonella* on tomatoes was promoted at a higher RH with some variation for different serovars (Rathinasabapathi, 2004; Shi et al., 2007). Also on apple surfaces *Salmonella* bacteria concentrations were found to decrease more rapidly at RH of 68% than at RH of 100% at both 4 °C and 15 °C (Tian et al., 2013). In addition, the inactivation of *Salmonella* in human urine during struvite drying was more efficient under RH of 40% than 80% at both 5 °C and 35 °C within a time window of 12 days (Bischel et al., 2016). In contrast, Park (Park et al., 2015) and Keller (Keller et al., 2013) found that *Salmonella* reduction levels were higher on eggshells or black pepper when they were stored at high RH conditions (85% or 97%) compared to an environment with low RH (43% or ≤40%), respectively. However, evidence also showed that the interaction between temperature and RH played a significant role in the inactivation of *Salmonella*, which makes it less clear to see the real and standalone effect of RH on this pathogen (Bischel et al., 2016; Iturriaga et al., 2003). *Salmonella* abundance on tomato or tomatillo surface dropped the most under a humidity of 75% at 30 °C but the least at 12 °C, relative to a humidity of 85% and 97% (Iturriaga et al., 2003). The findings from the current observational study with a varying time frame suggested that a higher hospitalization rate was associated with elevated RH above 60% for a period of 17 days. In addition, a positive relationship between moisture in soil (Chandler and Craven, 1980) and wastewater sludge (Yeager and Ward, 1981) and bacterial survival have been reported. Higher inherent moisture content in seafood has also been found to be a favorable condition for the growth and survival of *Salmonella* pathogen (Kumar et al., 2015). Thus, it is supported by this study that a humid environment was in favor of *Salmonella* proliferation.

There have been few studies on the association between rainfall and *Salmonella* morbidity. Some studies from Australia (Zhang et al., 2010; Stephen and Barnett, 2016; Zhang et al., 2008) reported inconsistent results with a positive association noted in subtropical and tropical cities (Zhang et al., 2010; Stephen and Barnett, 2016) and a negative association identified in a city with a Mediterranean climate (Zhang et al., 2008). Precipitation has been found to be a positively associated factor that affects the detection and density of *Salmonella* in produce and watershed (Strawn et al., 2013; Haley et al., 2009). We only found a positive association in the range from no rain to light rainfall. Groundwater formed by rainfall could be an ideal natural reservoir for maturation and incubation of pathogens before its entry to the host. In addition, higher volume of rainfall could increase runoff of surface water, which might facilitate in pathogen transport to fresh produce as well as livestock farm, along with sediment in which pathogens could persist for a material period (Czajkowska et al., 2005). Notwithstanding that heavy rainfall might increase the chance of microorganism dissemination by potential sewage overflow that contains high concentration of pathogens to surface water and soil, we found a decreased risk of *Salmonella* hospitalization with extreme rain, although there has also been evidence showing higher risk of salmonellosis was associated

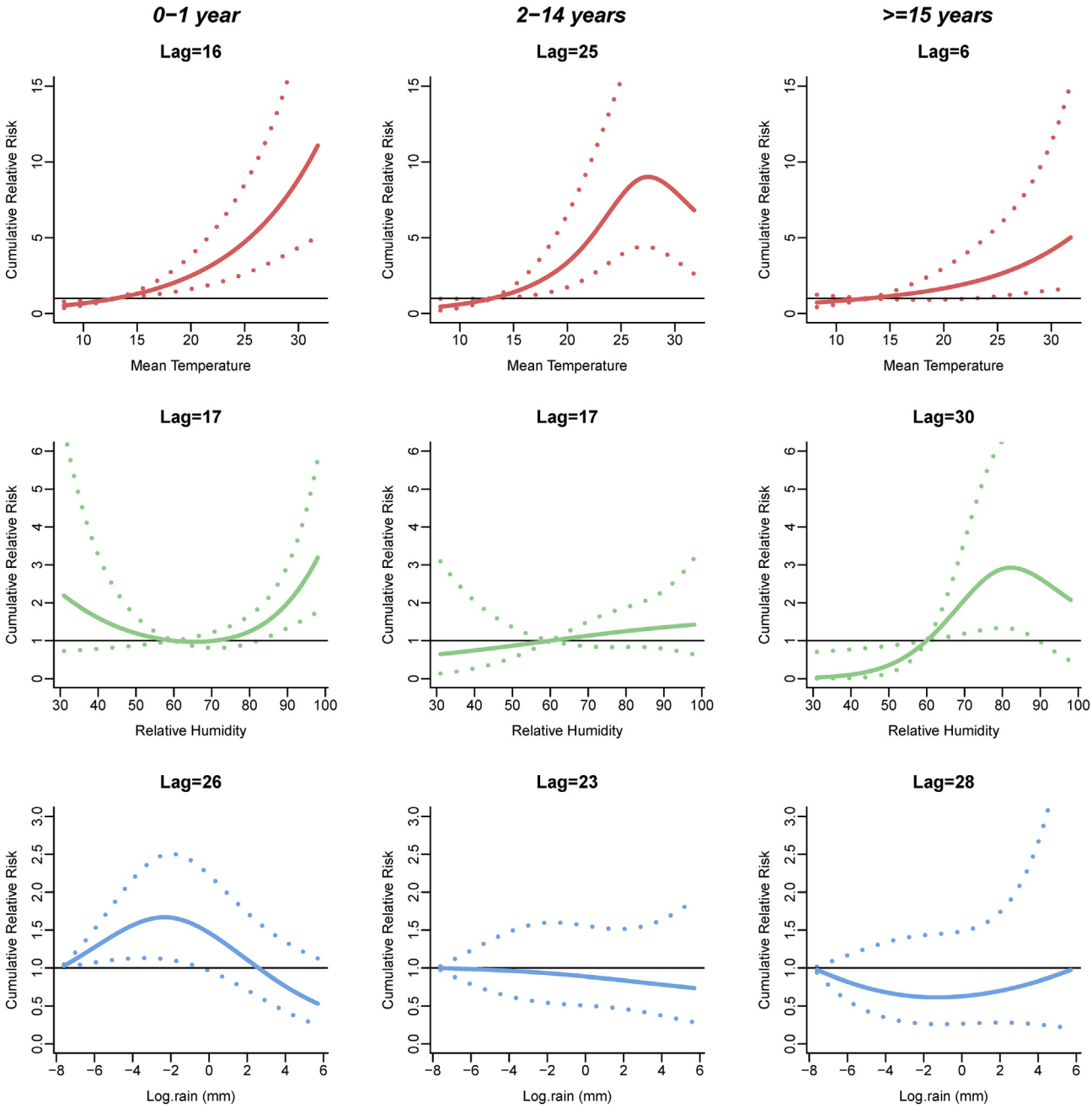

Fig. 4. Cumulative exposure-response associations of *Salmonella* hospitalizations with mean temperature, relative humidity and daily total rainfall for all age groups.

with extreme precipitation events (Jiang et al., 2015). One possible underlying reason is that heavy downpours, which could break pathogen dispersal by reshaping reservoirs into water currents, could also serve as a protective factor.

We found that the associations with weather variation were dominant among infants who accounted for 59.2% of all hospitalizations. Several underlying reasons may exist. An epidemiological study in the United States suggested that children aged under 1 year were at a higher risk of invasive salmonellosis compared to adults (Arshad et al., 2008). Previous evidence has shown that breastfeeding could significantly reduce the risk of *Salmonella* infection among infants (Jones et al., 2006). However, a population-based survey covering 90% of all infants born in Hong Kong in 2012 showed that the breastfeeding rate at 6 and 12 months of age of a child was only 32.7% and 14.2%, respectively (Department of Health, 2015). Consequently, most local infants lack protection from the passive IgG antibody transferred from breast milk (Simon et al., 2015). Furthermore, consumption of both powdered (Usera et al., 1996) and concentrated liquid (Jones et al., 2006) infant formula was found to be associated with higher rate of infant *Salmonella* infection. Therefore, bottle -fed infants in Hong Kong are more likely to have a higher risk of salmonellosis. In addition, older infants who attended daycare centers were prone to cross infection through caretakers who had been in contact with an infected child.

With mounting epidemiological evidence between the infection and weather variation, higher temperatures associated with climate change are likely to lead to increases in *Salmonella* hospitalizations in the absence of changes in other factors facilitating *Salmonella* infection. Unlike most important causes of morbidity and mortality, for which U-shaped associations with temperature have been found, *Salmonella* infections appear to consistently rise with temperatures over the range of temperatures recorded in the studied areas. Thus, unlike for other adverse health conditions there will be no drop in cold -related cases to

partially compensate for the projected increase in heat-related cases. Additionally, according to the Intergovernmental Panel on Climate Change, 7% more atmospheric moisture content could be retained with every 1 °C increase in air temperature (Intergovernmental Panel on Climate Change, 2014). In Hong Kong, higher temperatures in summer are generally accompanied by higher RH. Climate change may also result in changes in precipitation patterns (Intergovernmental Panel on Climate Change, 2014) that could also influence the humidity in the atmosphere and soil. A local study describing future rainfall variations projected that the frequency of precipitation is expected to decline while both annual total rainfall and intensity of daily rainfall are expected to increase in the 21st century (Lee et al., 2011). Consequently, higher volume of water content possibly induced by higher RH and more rain could facilitate the growth and survival of *Salmonella* in moisturized soil and manure (Warriner et al., 2009) that might impact on disease epidemics. Furthermore, antimicrobial resistant *Salmonella* has become an increasing threat to public health (Murphy et al., 2018; Williamson et al., 2017). About 8% of all non-typhoidal *Salmonella* cases in the United States presented a resistance pattern (Centers for Disease Control and Prevention, 2013) and these cases were more likely to be hospitalized due to more severe manifestations and less effective treatment. Antibiotic resistance of concern, together with climate change associated higher temperatures, could be considered as a mounting threat in relation to *Salmonella* infection.

A ten-year time-series with daily scale and a large hospitalization dataset covering 83% of all admissions in Hong Kong were adopted in the analysis, which enabled us to evaluate simultaneously the real-time and delayed effect of meteorological variation, by capturing the true incidence of severe cases of *Salmonella* infection as much as possible. Nonetheless, several limitations need to be acknowledged. First, outpatient cases and those who didn't need medical attention were not included in the analysis, which could underestimate the true incidence of the infection, since a large number of infected people recover without the need of hospitalization. However, the majority of severe cases in Hong Kong were covered by our study, which could be of more public health concern. Second, previous laboratory studies have noticed that distinct serotypes of *Salmonella* bacteria could be differently influenced by the environment (Rathinasabapathi, 2004; Shi et al., 2007; Hokunan et al., 2016; Kataoka et al., 2014). Therefore, the general classification of salmonellosis could possibly mask and improperly generalize the real association with meteorological variables for separate serovars. However, the laboratory surveillance data were not available in our study and further seroepidemiological studies are warranted to investigate the serovar-specific associations with meteorological parameters. Third, the current study was conducted in a single subtropical city, and our results may not be generalizable to areas with different climatic conditions.

5. Conclusions

Our study found that *Salmonella* morbidity in Hong Kong was strongly associated with short-term meteorological conditions. High temperatures playing a particularly important role, with risks at very high temperatures more than six-fold higher compared to low temperatures. High humidity was also important with an approximately two-fold higher risk with very high humidity relative to moderate humidity. Higher temperatures, and possibly higher humidity, associated with climate change will likely lead to increases in *Salmonella* morbidity in the absence of other changes. Greater attention will need to be paid to food safety, particularly during periods of hot and humid weather and more investigations are necessary on the role of precipitation in *Salmonella* infection.

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Declarations of interest

None.

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